

WE CLAIM:

1. A steam reformer adapted to receive a reformat feedstock and produce an at least substantially pure hydrogen stream therefrom, the steam reformer comprising:

5 a first reformation region including a reformation catalyst;

a second reformation region including a reformation catalyst;

wherein at least one of the reformation regions is adapted to produce a reformat stream comprising hydrogen and other gasses; and

10 a membrane region including a hydrogen-selective membrane, the membrane region being in fluid communication with the first and second reformation regions, and the hydrogen-selective membrane being adapted to receive the reformat stream and separate the reformat stream into an at least substantially pure hydrogen stream and a byproduct stream including a substantial portion of the other gasses.

15 2. The reformer of claim 1 wherein at least a portion of the second reformation region extends within the first reformation region.

20 3. The reformer of claim 2 wherein the membrane region physically separates the first reformation region from the second reformation region.

4. The reformer of claim 3 wherein the first reformation region, the second reformation region, and the membrane region are all contained within annular shells.

5. The reformer of claim 4 wherein the annular shell containing the membrane region is made of a hydrogen-selective material.

6. The reformer of claim 1 wherein the first reformation region is spaced apart from the second reformation region.

7. The reformer of claim 6 wherein the first reformation region is parallel to the second reformation region.

8. The reformer of claim 6 wherein the first reformation region is fluidly connected to the second reformation region through one or more conduits.

9. The reformer of claim 8 wherein the one or more conduits extend through a divider plate.

5 10. The reformer of claim 8 wherein the membrane region fluidly connects the first reformation region and the second reformation region.

10 11. The reformer of claim 10 wherein the membrane region is separated from the first and second reformation regions by a divider plate.

15 12. The reformer of claim 1 wherein the second reformation region further includes a polishing catalyst.

13. The reformer of claim 1 wherein the first and second reformation regions receive the reformat feedstock simultaneously.

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14. The reformer of claim 1 wherein the first reformation region is adapted to receive a first stream containing a carbon-containing fuel and steam and the second reformation region is adapted to receive a second stream containing hydrogen produced in the first reformation region.

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15. The reformer of claim 14 wherein the first stream flows in a concurrent direction with the second stream.

16. The reformer of claim 14 wherein the first stream flows in a countercurrent direction to the second stream.

17. The reformer of claim 1 wherein the hydrogen-selective membrane is planar.

18. The reformer of claim 1 wherein the hydrogen-selective membrane is annular in shape and forms a hydrogen-selective membrane tube.

19. The reformer of claim 18 wherein the second reformation region is contained within the hydrogen-selective membrane tube.

5 20. The reformer of claim 1 wherein the membrane region contains a plurality of hydrogen-selective membranes.

10 21. The reformer of claim 20 wherein the membrane region contains a plurality of hydrogen-selective membrane tubes.

15 22. The reformer of claim 21 wherein each of the hydrogen-selective membrane tubes contains a reformation region including a reformation catalyst.

23. The reformer of claim 21 wherein each of the hydrogen-selective membrane tubes is contained within a reformation region including a reformation catalyst.

24. The reformer of claim 1 wherein between approximately 50 cm² and 1300 cm² of hydrogen-selective membrane is exposed to the reformat stream.

5 25. The reformer of claim 1 wherein between approximately 50 cm² and 850 cm² of hydrogen-selective membrane is exposed to the reformat stream.

10 26. The reformer of claim 1 wherein between approximately 80 cm² and 200 cm² of hydrogen-selective membrane is exposed to the reformat stream.

15 27. The reformer of claim 1 further including a combustion region adapted to provide heat to the reformer, the combustion region being further adapted to combust at least a portion of the byproduct stream.

20 28. The reformer of claim 1 in combination with a fuel cell stack, wherein the reformer is further adapted to provide the at least substantially pure hydrogen stream to the fuel cell stack, the fuel cell stack including a plurality of fuel cells adapted to receive the substantially pure hydrogen stream and produce an electric current therefrom.

29. The reformer of claim 28 in combination with an electric motor,
wherein the fuel cell stack is adapted to provide an electric current to the electric motor.

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30. A steam reformer comprising:

a plurality of annular reformation regions housed within a shell, each
reformation region including a reformation catalyst adapted to produce hydrogen from a
gas mixture including carbon-containing fuel and steam and wherein at least one of said
annular reformation regions houses at least one annular hydrogen-selective membrane
forming a hydrogen-selective membrane tube adapted to separate a mixed-gas stream into
an at least substantially pure hydrogen stream and a byproduct stream including a
substantial portion of the other gasses.

31. The reformer of claim 30 wherein, in the reformation region housing
the at least one annular hydrogen-selective membrane, the reformation catalyst is
contained within the annular hydrogen-selective membrane.

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32. The reformer of claim 31 wherein the reformation catalyst is
contained within an annular shell within the hydrogen-selective membrane.

33. The reformer of claim 30 wherein, in the reformation region housing the at least one annular hydrogen-selective membrane, the reformation catalyst is exterior to the hydrogen-selective membrane.

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34. The reformer of claim 30 wherein, in the reformation region housing the at least one annular hydrogen-selective membrane, the reformation catalyst is both exterior to and contained within the annular hydrogen-selective membrane.

35. The reformer of claim 34 wherein the reformation catalyst within the annular hydrogen-selective membrane is contained within an annular shell.

36. The reformer of claim 30 wherein between approximately 80 cm² and 1300 cm² of hydrogen-selective membrane is exposed to the reformat stream.

37. The reformer of claim 30 wherein between approximately 200 cm² and 1300 cm² of hydrogen-selective membrane is exposed to the reformat stream.

38. The reformer of claim 30 wherein between approximately 80 cm² and 200 cm² of hydrogen-selective membrane is exposed to the reformat stream.

5 39. The reformer of claim 30 further including a combustion region adapted to provide heat to the reformer, the combustion region being further adapted to combust at least a portion of the byproduct stream.

10 40. The reformer of claim 30 in combination with a fuel cell stack wherein the reformer is further adapted to provide an at least substantially pure hydrogen stream to the fuel cell stack, the fuel cell stack including a plurality of fuel cells adapted to receive the substantially pure hydrogen stream and produce an electric current therefrom.

15 41. The reformer of claim 40 in combination with an electric motor wherein the fuel cell stack is adapted to provide an electric current to the electric motor.

20 42. The reformer of claim 30 wherein the carbon containing fuel includes gasoline.

43. A steam reformer comprising:

a reformation region adapted to receive a reformation feedstock and

produce a mixed gas stream containing hydrogen and other gasses therefrom;

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a separation region adapted to expose the mixed gas stream to a plurality of

hydrogen-selective membranes to separate the mixed gas stream into a substantially pure

hydrogen stream and a byproduct stream containing at least a substantial portion of the

other gasses, wherein the hydrogen-selective membranes have a combined surface area in

the range of approximately 50 cm² and approximately 1300 cm².

44. The reformer of claim 43 wherein the hydrogen-selective

membranes are annular in shape and form hydrogen-selective membrane tubes.

45. The reformer of claim 43 wherein the hydrogen-selective

membranes have a combined surface area in the range of approximately 50 cm² and

approximately 800 cm².

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46. The reformer of claim 43 further including a combustion region adapted to provide heat to the reformer, the combustion region being further adapted to combust at least a portion of the by product stream.

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47. The reformer of claim 43 in combination with a fuel cell stack, wherein the reformer is further adapted to provide an at least substantially pure hydrogen stream to the fuel cell stack, the fuel cell stack including a plurality of fuel cells adapted to receive the substantially pure hydrogen stream and produce an electric current therefrom.

48. The reformer of claim 47 in combination with an electric motor wherein the fuel cell stack is adapted to provide electric current to the electric motor.

49. A fuel cell system comprising:

a steam reformer comprising

a first reformation region containing a reformation catalyst;

a second reformation region containing a reformation catalyst;

5 wherein at least one of said first and second reformation regions is adapted to receive a reformation feedstock and produce a mixed gas stream containing hydrogen and other gasses therefrom;

10 a separation region adapted to expose the mixed gas stream to at least one of a plurality of hydrogen-selective membranes adapted to separate the mixed gas stream into an at least substantially pure hydrogen stream and a byproduct stream containing at least a substantial portion of the other gasses, wherein the separation region is in fluid communication with the first and second reformation regions;

15 a combustion region adapted to provide heat to the reformer, the combustion region being further adapted to combust at least a portion of the byproduct stream;

a fuel cell stack including a plurality of fuel cells adapted to receive the at least substantially pure hydrogen stream and produce an electric current therefrom.

20 50. The reformer of claim 49 wherein between approximately 50 cm² and 1300 cm² of hydrogen-selective membrane is exposed to the reformat stream.

51. The reformer of claim 49 wherein between approximately 50 cm² and 850 cm² of hydrogen-selective membrane is exposed to the reformat stream.

5 52. The reformer of claim 49 wherein between approximately 80 cm² and 200 cm² of hydrogen-selective membrane is exposed to the reformat stream.

10 53. The reformer of claim 49 wherein the at least one of the plurality of hydrogen-selective membranes is annular in shape and forms a hydrogen-selective membrane tube.

15 54. The reformer of claim 49 wherein the at least one of the plurality of hydrogen-selective membranes is planar in shape.

20 55. The fuel cell system of claim 49 in combination with an electric motor wherein the fuel cell stack is adapted to provide electric current to the electric motor.